given by,

$$\eta=1-\tau_{Yb\text{-}Er}/\tau_{Yb}$$

where $\tau_{Yb\text{-}Er}$ is the measured lifetime of the Yb^{3+} $^2F_{5/2}$ level in a codoped sample with Er (measured at 1.79×10^{-3} seconds) and τ_{Yb} is the measured lifetime of Yb^{3+} $^2F_{5/2}$ level in a sample with no erbium (measured at 1.37×10^{-3} seconds). The value of η was thus calculated to be 0.87. Additional description of this modeling method, but applied to silicate glasses having greatly inferior laser properties, is provided in "*Rigorous Scalar Modeling of Er and Er/Yb-doped Waveguide Lasers*" (Veasey, Gary, Amin) which is incorporated by reference.

A2 concl

Replace the paragraph beginning at page 14, line 3, with the following:

Another embodiment of the invention is directed to modifying or tuning the wavelengths of a waveguide or waveguides in a substrate. This can be done by heating of the substrate which will alter the wavelengths of the waveguides therein. Where the substrate containing waveguide(s) is part of a laser device, it was expected that the heating thereof would increase the wavelength of the laser due to expansion of the diffraction grating periodicity. What the inventors have discovered, however, is that for substrates containing solid state waveguides provided as channels in the substrate, as discussed above, heating has a fine tuning effect on altering the wavelength of the waveguide. Thus, for example, while semiconductor DFB lasers are increased in wavelength upon heating, the increase of wavelength upon heating of laser devices with waveguides according to this invention is significantly lower as a function of the temperature, e.g., the increase of wavelength as a function of temperature is roughly 15 times lower than that for semiconductor DFB lasers. The inventors have discovered that while heating expands the glass increasing the wavelength, the extent of increase is offset by the temperature effecting a decrease of the refractive index with temperature of the glass forming the waveguide(s). The theory behind this and experiments supporting it are described in the Journal of Non-Crystalline solids (JNCS) article "*Rigorous Scalar Modeling of Er and Er/Yb-doped Waveguide Lasers*" (Veasey, Gary, Amin), particularly at page 14 and in Figure 14. According to the invention, therefore, the temperature control requirements for maintaining a stable wavelength are relaxed with the waveguides according to the invention, i.e., a variance in the temperature will not have as significant effect on the tuning, allowing finer tuning thereof.

A3

Replace the paragraph beginning at page 16, line 7, with the following:

Waveguides prepared in accordance with any of the above descriptions, having multiple or single waveguides of the same or differing wavelengths, are useful in preparing lasers by providing the waveguide with a grating pattern. Examples of methods for producing lasers from waveguides of the type discussed above are provided in "*Arrays of Distributed-Bragg-Reflector Waveguide Lasers at 1536 nm in YB/ER-co-doped Phosphate Glass*" (Veasey, Funk, Sanford, Hayden); "*170 mW eb at 1540 nm from an Erbium/Ytterbium Co-doped Glass Waveguide Laser*" (Funk, Veasey, Peters, Sanford, Hayden); and "*Ion-exchanged Er3+/YB3+ Glass Waveguide Lasers in Silicate Glasses*" (Peters, Veasey, Funk, Sanford, Houde-Walter, Hayden), which are incorporated herein by reference. These references also discuss methods generally applicable to production of waveguides and those teachings are additionally incorporated by reference herein. In general, lasers are fabricated from the waveguides by providing a reflecting element at both ends of the waveguide. The reflecting elements can be those known in the art. Included as embodiments are waveguides having optically polished ends provided with mirrors on both ends. An additional preferred embodiment, is providing the waveguide with a diffraction grating on one end of the waveguide. In a preferred embodiment, the grating is provided by etching onto the glass substrate containing the waveguide(s). One preferred type of grating is a DBR grating as known in the art. Such gratings are advantageous because they provide a narrow reflection line and thus provide a laser with a narrower wavelength.

A4

Replace the paragraph beginning at page 19, line 4, with the following:

Another embodiment is directed to segment having forty laser waveguides organized in eight sets. The segments may be processed, for example, according to one of the methods described in "*Arrays of Distributed-Bragg-Reflector Waveguide Lasers at 1536 nm in YB/ER-co-doped Phosphate Glass*" (Veasey, Funk, Sanford, Hayden); "*170 mW eb at 1540 nm from an Erbium/Ytterbium Co-doped Glass Waveguide Laser*" (Funk, Veasey, Peters, Sanford, Hayden); and/or "*Ion-exchanged Er3+/YB3+ Glass Waveguide Lasers in Silicate Glasses*" (Peters, Veasey, Funk, Sanford, Houde-Walter, Hayden), to form a plurality of sets (e.g., in one embodiment, each set has five waveguides; and in another embodiment, each set is used

A5

such that one waveguide is used, and the other four provide redundancy in case one or more do not function properly). In this embodiment, each set is overlaid with a diffraction Bragg reflector (DBR) which forms one mirror of a laser, and each DBR is fabricated to a different spacing designed to resonate at a different output wavelength. In one embodiment, only eight of the forty waveguides are used for eight respective lasers; the others are provided for redundancy. Thus, the DBR for one set is designed such that all five waveguides of that set will lase at the same wavelength, and any one of these waveguides can be used as the laser for the desired wavelength of that set. However, each of the DBRs are designed for a different output wavelength. Thus the segment is designed to provide eight lasing waveguides each outputting light at one of eight predetermined wavelengths that are tuned by the eight DBRs. In one embodiment, an input mirror (e.g., a multi-layer dielectric mirror) is deposited on an end face of segment opposite the DBRs. In other embodiments, an external mirror is placed against that face to provide the feedback function desired for lasing and the pump-light-launching function. The input mirror is designed to transmit as much light as possible at the pump wavelength (in one embodiment, 0.98 micrometers), while reflecting as much light as possible at the output wavelength (in one embodiment, a selected wavelength near 1.54 micrometers as tuned by the corresponding to the DBR). In one embodiment, the segment is used in a communications system that uses dense wavelength-division multiplexing (DWDM), wherein, for example, forty different wavelengths are each modulated to carry a different channel of information, and then all forty channels are passed on a single optic fiber. In one such embodiment, each channel's wavelength differs from the next channel's wavelength by 0.8 nanometers. Thus, for example, a segment could be designed to output laser light at wavelengths of 1.5360, 1.5368, 1.5376, 1.5384, 1.5400, 1.5408 and 1.5416 micrometers. Other segments of a system could be designed to lase at eight other channel wavelengths. Thus, a forty-channel system only needs five such different part numbers (i.e., unique part designs), rather than forty different part numbers in conventional approaches.

A5 cont

Replace the paragraph beginning at page 26, line 27, with the following:

To test the Yb/Er-codoped lasers, we typically pumped the waveguides using a tunable Ti:Al_2O_3 laser. Figure 1 shows a schematic of the laser measurement setup. Placing broadband dielectric mirrors on the polished waveguide end faces formed the laser cavities.

A6

A4 cont

The mirrors were held in place by small spring clips with index matching oil between the end facet and the mirror. The pump laser light was launched through one of the mirrors with a 4X microscope objective. The laser output and unabsorbed pump light were collimated with a 16X microscope objective and separated using filters. The mirror through which the pump light was launched had a reflectance of >99.9 % and 15 % at 1540 and 960 nm, respectively. The output coupler had a reflectance of 80 % at 1540 nm and 15 % at 960 nm. Neither the waveguide length nor the cavity output couplings were optimized. Additional information for this example can be found in the JNCS article "*Rigorous Scalar Modeling of Er and Er/Yb-doped Waveguide Lasers*" (Veasey, Gary, Amin).

Replace the paragraph beginning at page 31, line 22, with the following:

A7

Before the DBR grating was formed by transferring the photoresist pattern into the glass by Ar-ion sputtering, 40 nm of Cr was deposited on the surface with the specimen inclined 60° to the electron-beam evaporation source. Mounting the specimen in this way causes Cr to accumulate only on the tops of the grating lines and not in the grooves, thus providing a durable etch mask. The grating was etched in the glass for 20 minutes using a reactive ion etching system with a 6.67 Pa (50 mTorr) Ar-ion plasma. The low-pressure plasma created a large self-bias voltage of 1700 V when running at 365 W of coupled power with frequency 13.5 MHZ. The electrode spacing was 3.2 cm. After etching, the sample was cleaned ultrasonically in photoresist stripper at 85°C. Fig. 1 of "*Rigorous Scalar Modeling of Er and Er/Yb-doped Waveguide Lasers*" (Veasey, Gary, Amin) is an illustration of the completed DBR laser array.

Replace the paragraph beginning at page 32, line 3, with the following:

A8

The waveguide laser cavities were formed by placing a thin, highly reflecting (R=99.9% at 1540 nm, R=15% at 997 nm) dielectric mirror on the pump input facet. The mirror was held in place by a spring clip, and index-matching fluid was used between the mirror and the waveguide facet. The DBR grating was used as the laser output coupler. We tested the laser by coupling light from a Ti-Al_2O_2 laser turned to a wavelength of 977 nm using a 4x objective lens with a numerical aperture of 0.1. The launching efficiency was estimated to be between 65 and 71 percent. To determine the launching efficiency we

measured the Fresnel reflectance of the input mirror, the loss of the launching objective, and the excess coupling loss. Fig. 10 of "*Rigorous Scalar Modeling of Er and Er/Yb-doped Waveguide Lasers*" (Veasey, Gary, Amin) shows the laser output power as a function of launched pump power and the spectrum of the laser. The waveguide diffusion aperture for this waveguide was 8 μm. The slope efficiency as a function of launched pump power is calculated to by 26 percent when we take the coupling factor to be 71 percent.

A7 amd

Replace the paragraph beginning at page 32, line 25, with the following:

To investigate the longitudinal mode structure of the laser we coupled the laser output into an optical fiber scanning Fabry-Perot interferometer with a free spectral range of 124 GHz. Fig. 11 of "*Rigorous Scalar Modeling of Er and Er/Yb-doped Waveguide Lasers*" (Veasey, Gary, Amin) shows that the laser operated on a single longitudinal mode when the coupled pump power did not exceed 300 mW. The laser was robustly single frequency with TE polarization, and no mode hopping was observed. The inset in Fig. 11 shows that a second longitudinal mode appeared when coupled pump power exceeded 300 mW. In this pump regime, the laser was unstable and exhibited mode hopping, single-frequency operation, and dual-frequency operations. By measuring the frequency spacing between the longitudinal modes we determined that the physical length of the laser cavity was 1.4 cm.

A8

Replace the paragraph beginning at page 33, line 5, with the following:

We measured the linewidth of the laser using a conventional self-heterodyne configuration with a 75 MHZ frequency shift. The path length difference between the two arms was 10 km corresponding to linewidth resolution limit of 30 kHz for a gaussian line shape. Optical isolations were used in both arms to prevent optical linewidth narrowing due to feedback; however, the output end of the laser was not beveled. Fig. 12 of "*Rigorous Scalar Modeling of Er and Er/Yb-doped Waveguide Lasers*" (Veasey, Gary, Amin) shows the self-heterodyne spectrum. The laser linewidth we obtained from this measurement was 500 kHz.

A9

Replace the paragraph beginning at page 33, line 12, with the following:

Finally, we measured the laser wavelengths of other waveguides on the chip using an

A10

automatic spectrum analyzer with a resolution of 0.1 nm. Seven of the eleven waveguides on the chip exhibited laser oscillation. The waveguides formed through the smaller apertures did not achieve threshold because the smaller mode volumes caused a reduction of the gain such that the 45 percent transmittance loss of grating could not be overcome. Fig. A5 in "*Arrays of Distributed-Bragg-Reflector Waveguide Lasers at 1536 nm in YB/ER-co-doped Phosphate Glass*" (Veasey, Funk, Sanford, Hayden) shows the change in wavelength trend as we scanned the waveguides. The wavelength increases as the diffusion aperture width increases, which is consistent with increasing effective index as the aperture width increases.

A10 cont'd

Replace the paragraph beginning at page 35, line 11, with the following:

A11

In another embodiment, the refractive index as a function of position within the exchanged sample was analyzed using a refractive near-field scanning method. Fig. B1 in "*170 mW eb at 1540 nm from an Erbium/Ytterbium Co-doped Glass Waveguide Laser*" (Funk, Veasey, Peters, Sanford, Hayden) shows the index depth profile at the center of the waveguide formed with the 6.5 μm mask aperture for a wavelength of 633 nm. This method allows the relative position and absolute index values to be determined with an accuracy of 0.7 μm and 0.001, respectively.

Replace the paragraph beginning at page 35, line 26, with the following:

A12

In another embodiment, the device was pumped with a Ti^{3+} sapphire laser. The waveguide laser cavities were formed by placing thin dielectric mirrors on the polished waveguide end faces. The mirrors were held in place by small spring clips, and index matching oil was used between the mirror and waveguide end faces to reduce losses. The pump laser was launched through one of the mirrors with a 4X microscope objective. The laser output and unabsorbed pump were collimated with a 16X microscope objective and separated using filters. The laser cavity was 20 mm in length. The mirror through which the pump was launched had reflectivities of >99.9% and 15% at 1536 and 980 nm, respectively. The output coupler had a reflectivity of 80% at 1536 nm and transmitted 85% of the incident pump power. Neither the waveguide length nor the cavity output coupling has been optimized. The launching efficiency was estimated to be ≤ 71%, including losses due to the transmission of the input mirror and launching objective. The laser output power

characteristics for two different pump wavelengths are illustrated in Fig. B2 of "*170 mW eb at 1540 nm from an Erbium/Ytterbium Co-doped Glass Waveguide Laser*" (Funk, Veasey, Peters, Sanford, Hayden). When pumped at 979 nm, the launched pump power threshold was 51 mW. A maximum output power of 168 mW was obtained for 611 mW of launched 979 nm pump power. A lower threshold could be obtained by turning the pump laser off of the Yb^{3-} absorption peak. For a pump wavelength of 960 nm, the threshold was 23 mW. The slope efficiency for both pump wavelengths was ~ 28%.

A12 amd

Replace the paragraph beginning at page 36, line 14, with the following:

Using the broad-band cavity described above, the Er^{3+}/Yb^{3+} laser usually operated at several wavelengths simultaneously. A typical laser spectrum showing simultaneous operation at 1536.0, 1540.7 and 1544.8 nm is depicted in Fig. B3 of "*170 mW eb at 1540 nm from an Erbium/Ytterbium Co-doped Glass Waveguide Laser*" (Funk, Veasey, Peters, Sanford, Hayden). The wavelength(s) of operation could be shifted by passing some of the collimated 1.5 μm laser output through a prism and reflecting it back through the prism and into the waveguide using a dielectric mirror. This formed a weakly-coupled, external cavity. By rotating the prism, it was possible to produce wavelengths ranging from 1536 to 1595 nm.

A13

Replace the paragraph beginning at page 36, line 22, with the following:

A common feature of many three-level rare-earth lasers is sustained relaxation oscillations which can be caused by small fluctuations in the pump laser power. Fluctuations in output power at frequencies ranging from ~ 0.5 to 1.5 MHZ were observed in this laser. The amplitude of the fluctuations decreased with pump power. Figure B4 in "*170 mW eb at 1540 nm from an Erbium/Ytterbium Co-doped Glass Waveguide Laser*" (Funk, Veasey, Peters, Sanford, Hayden) shows the output power as a function of time for pump power levels just above threshold and 9.4 times threshold. At the low pump power, the output power fluctuations of ~ 30% (peak to peak) of the average power were observed. At the high pump power, the fluctuations decreased to ~ 5% (peak to peak) of the average power. The Ti^{3+}:sapphire pump laser exhibited output power fluctuations of ~ 2-3%. Using a diode laser as the pump source should result in much quieter operation of the Er^{3+} laser.

A14

Replace the paragraph beginning at page 39, line 10, with the following:

The laser performance was investigated as a function of device length as well as output coupler reflectance. Figure C1 in "*Ion-exchanged Er3+/YB3+ Glass Waveguide Lasers in Silicate Glasses*" (Peters, Veasey, Funk, Sanford, Houde-Walter, Hayden) shows a plot of laser signal power vs. launched pump power for two different output couplers, for a 1.68 cm long device fabricated in the glass with 5 Yb^{3+} per Er^{3+} ion. The slope efficiencies and laser thresholds were determined by fitting a line to the laser data. The lowest threshold was achieved when using a 98% reflector as output coupler. This device lased with a launched pump power threshold of approximately 59 mW. The slope efficiency of this device was 2.0% with respect to launched pump power. The highest slope efficiency was realized with a 70% reflector used as an output coupler. In this case, a slope efficiency of 6.5% was achieved with a launched pump power threshold of 86 mW. For a launched pump power of 398 mW, this laser produced 19.6 mW of output power.

A15

Replace the paragraph beginning at page 39, line 22, with the following:

A plot of slope efficiency vs. output coupler reflectance for each host glass appears in Figure C2 of "*Ion-exchanged Er3+/YB3+ Glass Waveguide Lasers in Silicate Glasses*" (Peters, Veasey, Funk, Sanford, Houde-Walter, Hayden). Data for device lengths in each glass which were experimentally determined to give the highest slope efficiency are plotted. Highest slope efficiency performance in each host is also compared in Table 1.

A16

Page 40, after line 16, insert the following new section:

A17

<u>Brief Description of the Drawings</u>

Figure 1 shows a schematic of the laser measurement setup.

Figure 2 shows an embodiment of the fabrication of a single-frequency 1.32-1.4 um laser in Nd-doped phosphate glass fused to La-doped glass.

Delete all the pages which appear as Appendices A-E of the disclosure following the Abstract.